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SPECTRAL INTENSITY VARIATIONS WITH TIME IN

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SPECIFIC SOLAR FLARE EVENTS AND RADIATION DOSES

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ABSTRACT

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Variations of the spectra of specific energetic flare particle events are considered, and an estimate of the doses in free space for different shielding thicknesses for the events of the highly active period May 1959 to November 1960 is given. The high energy part of the spectra ($E > 20$ Mev), because of minimum amounts of shielding being present and because of the relatively low intensities behind such shielding, is mainly important for effects on man. With respect to effects on material and sensitive electronic devices, attention is given to low energy protons in the Mev range, which are observed since late 1960 to be present in appreciably higher intensity during proton events associated with large magnetic storms. Under the assumption that particles $E > 1$ Mev arriving in such large numbers as in the November 12, 1960, and in July 12, 1961, events, are a usual feature of solar events accompanied by large magnetic storms, fluxes between 4×10^{11} to 10^{12} protons per cm^2 are obtained for the $1\frac{1}{2}$ year period May 1959 to November 1960. These proton numbers and the doses are threshold doses for permanent or transient effects on the surface or in thin sheets of sensitive materials and devices. The intensities are in the same order of magnitude as the intensity of low energy protons in the maxima of the belts. For long-term excursions during solar activity years these low energy protons may have to be taken into account with respect to the selection of surface materials and protection of sensitive devices especially if the spacecraft approaches the sun more closely.

AUTHOR

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By Trutz Foelsche*

INTRODUCTION

It is intended in this paper to treat some details of solar proton spectra and their variations with time to indicate numerically doses on the surface of matter or behind different amounts of shielding over extended periods of solar activity. Also the more recently detected low energy parts of the spectra are discussed. In these low energy parts, around 1 Mev, the fluxes are higher and may amount with time to doses which may have effects on materials and sensitive devices directly exposed to this radiation. Effects and threshold doses with respect to materials are briefly summarized. The particles of thermal energy or low energy in the kev range which constitute the main component of the solar wind - or of dense solar plasma clouds ejected during flare events - are considered only insofar as they influence the propagation of higher energy particles with their magnetic fields according to present theories.

For more convenience it may be useful to recall briefly the ranges of protons in matter in the energy range from 200 kev upward. (See table I.) To retain these ranges in mind and to recognize their possible significance, it may be mentioned:

200 kev protons penetrate just the junction layer of unprotected solar cells, which lies in about 1 to 2μ depth from the surface.

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1 Mev protons penetrate just the hull of the Echo I and Echo II satellites, which were in the order of 1/2 or 0.7 mil, respectively (12 to 18μ).

20 Mev protons penetrate a heavy spacesuit of 1.5 to 3 mm (1500 to 3000μ) thickness.

100 Mev protons penetrate the trunk of the unprotected body up to 1/2 or 1/4 of its depth. They are shielded by a layer of 10 cm water except for penetrating secondaries which are produced in nuclear collisions.

1000 Mev protons penetrate the wall of a space capsule and man's body even if heaviest shielding is provided, especially with their secondaries.

I. SPECTRA AND TIME PROFILES OF INTENSITIES, PARTICULARLY, HIGH ENERGY PART OF THE SPECTRA

The higher energy part of the solar proton spectra, say the intensities of particles $E > 20$ Mev, which could be exclusively measured during periods prior to 1960 are considered first.

These particles are less intense and should be chiefly important for their effects on man, who is more sensitive to radiation than nonliving matter. Man should also generally be protected in space by some millimeters of material. Thus, the low energy particles which cannot penetrate this thickness might be neglected in discussing effects on man.

Figure 1 shows the time scale of a series of intense events in July 1959 and serves to explain how the spectra at different times can be derived. The July 1959 events as a whole were probably the largest event in size, i.e., in content of particles, observed in the last solar cycle. Of course, it was not the largest in energy of particles. The duration of these July events extends over 18 days, the maximum phase of one event extends over a period of 1 to 2 days.

The upper section shows the riometer absorption in the northern stations (Reid and Leinbach 1960) which is about proportional to the square root of the flux of particles of energy $\geqq$20 Mev. Riometers measure the electron density in the lower ionosphere produced by flare protons by measuring the absorption of galactic radio noise in the 30 and 50 Mc band.

The lower section gives the particle flux $E \geqq 80$ to some 100 Mev, measured directly with geiger counters and ionization chambers in balloons, above Minnesota in this case (Winckler, Bhavsar, Peterson 1960) and above Resolute Bay (Anderson, Enemark 1960) near the magnetic North pole, during the declining phase of the events. In later events, from 1960 on, the low energy parts of the spectra were also measured in rockets or satellites and are more reliable because riometer measurements are not unambiguous.

In high energy events the intensity in a third energy range of the spectra can be measured, namely in the energy range >1 Bev with neutron monitors at sea level. For instance the third event, that on July 16, produced a slight increase in neutrons at sea level in very high southern and northern magnetic latitudes.

We have, thus, the intensities in three ranges of energy from which the spectra at particular times can be composed, so far these three ranges of energy are measured simultaneously.

Figure 2 shows proton spectra for the November 12, 1960, event. On the abscissa are the energies and on the ordinate the flux of particles above these energies. These spectra are average spectra for three different times - 5, 10, and 27 hours after the flare - based on the measurements given in the references, Fichtel and Guss 1962; Ogilvie, Bryant, Davis 1962; Van Allen, Lin 1960; Winckler, et al. 1961; Steljes, Carmichael, McCracken 1961. Details on the composition of these and other mentioned spectra and the calculation of doses in figure 4 and table II are given in the references (Foelsche 1962 and 1963). The spectra for the May and July 1959 events exhibit very similar features but are very uncertain in the energy range below 30 Mev. For orientation also, the inner belt spectrum and Galactic Cosmic proton spectrum during solar minimum are indicated.

We note the following features:

(1) The fluxes in the very high range 1 Bev are very low - in the order of Galactic Cosmic Ray background of few particles/cm^2-sec - except in the February 1956 high energy event during the initial phase. At 20 Mev the fluxes are higher by about 3 to 4 powers of 10.

It should be mentioned here also the enormous flux of particles of very low energy $E > 200$ kev $\approx 3 \times 10^5/cm^2$-sec-ster or $3 \times 10^6/cm^2$-sec. There is no doubt that these fluxes were real. These low energy proton fluxes are in the order of low energy proton fluxes in the Van Allen belt. They are discussed later on.

(2) The spectra for low and medium energy events fall off steeply with energy, especially above 100 Mev, and are steeper than in the inner Van Allen belt. Above 100 Mev there are only a few particles left; that means most particles can be cut off by about 10g/cm^2 of shielding.

Figure 3 shows the time profiles of intensities of protons of different energy for the same event, derived from these spectra. The intensities $E > 20$ Mev are taken from reference: Freier and Webber 1963.

We note:

The intensities of high energy particles fall off also with time rather rapidly (see also the February 1956 event), and the intensities in the very low energy range $E \leqq 20$ Mev stay on at a maximum for periods up to about 24 hours in this event.

From the steep decreasing slope of the spectra and the long duration of particles of low energy, we can thus conclude that the main dose during the event is produced in the first few g/cm^2 of material or of the unprotected body and that the dose decreases very steeply with increasing depth of the material. This decrease is less pronounced in the inner Van Allen belt because the proton spectra of the magnetically trapped protons are harder than those of most solar events.

In figure 4 are shown doses as a function of shielding for the largest events observed in the last solar cycle neglecting self-shielding of the body.

On the abscissa is given the thickness of the spherical shield in g/cm^2 or cm water, on the ordinate the dose measured in a small ionization chamber in the center of these empty spherical shells.

It should be mentioned that these are estimated upper and lower limits of doses, since the spectra are not equally well-known for all times especially in the events of 1959. They are considered as trustworthy within a factor of 2.

If a man's body is placed into the sphere it has to be taken into account that organs on the surface, as in the depth of the body, are protected from one or all sides by the body itself. Thus an inner organ receives a dose which can only be estimated from figure 4 by adding to the outer shield thickness the average thickness of the surrounding tissue which might be in the order of 10 to $15 g/cm^2$. Also the doses on the surface are substantially lower than those read from figure 4, when only the outer shield is taken into account. A fair approximation of doses received on organs on the surface, as skin, eyes, and gonads, is obtained by dividing the reading by a factor of 2 and thus neglecting the radiation from one side or from a solid angle 2π.

Table II summarizes the flare doses accumulated during an extended period of of $1\frac{1}{2}$ years of high solar activity from May 1959 to November 1960. In the third column the approximate dose on the surface of a man's body is given, if he is placed into the spherical shell, taking into account self-shielding of the body by a factor of 1/2.

The doses range from about 6000 rad on the surface of the body, inside a thin distant spherical shield, down to about 200 rad on his surface inside 6 cm water shield.

In the center of the body the dose accumulated in $1\frac{1}{2}$ years would have been only 30 to 40 rad at an outer shield thickness of 0.5 to 6g/cm^2. The depth doses from the unique energetic February 1956 event are about 50 rad, not taking into account secondaries having in part higher RBE.

The surface doses with an outer shield of 1/2 g/cm^2 can have damaging effects on the eyes, the skin, and gonads. Protection by 10g/cm^2 might be at least provided for the eyes during flare events in long-term excursions. Also the doses received in crossing the Van Allen belts and from galactic cosmic radiation have to be added. The total doses of some 1000 rad behind low shielding and outside the Van Allen belts are, however, in an order of magnitude, which should hardly have significant effects on materials inside this shielding, except on photo films, or except of transient effects on sensitive materials and electronic devices.

It may be mentioned that this conclusion is considered as valid for orbits in distances from the sun comparable to the distance of the earth. Close to the sun much higher intensities should be obtained. It may be mentioned furthermore that these conclusions are based on limited experience during the last solar cycle and that events of larger flux cannot be excluded. Their occurrence should be, however, rare. They were apparently not observed during the present solar cycle, which was the most sunspot active cycle in the past 80 years.

II. THE LOW ENERGY PART OF THE SPECTRA

In the second part of this survey it is intended to discuss the low energy part of the spectra, especially the high intensities of particles of about 1 Mev energy.

Protons of such low energy, which come to rest in high altitudes, are not very effective in producing absorption at 30 MC and thus contribute only weakly to the radio noise absorption at 30 MC measured by riometers, or to the absorption in the lower ionosphere measured by the scattering network of Bailey at the same frequency.

The first direct measurement of low energy particles was made during the November 1960 events with rockets from Fort Churchill at about 85^{o} magnetic latitude.

In the November 12, 1960 events, the high fluxes of particles $E > 200$ kev and $E > 1$ Mev were 3×10^5 and 6×10^4 proton/cm^2-sec-ster, respectively, and lasted for about 24 hours, as mentioned before.

The next major event group during the declining phase of the present solar cycle occurred in the week after July 12, 1961, and again showed extreme high fluxes, mainly after the sudden commencement of the severe magnetic storm accompanying the first two events. They lasted, of course, in this case only for 6 to 12 hours with a pronounced peak some hours after the sudden commencement. This time the low energy particles were recorded by Satellite Injun I at an altitude of about 1000 km in northern latitudes, still inside the magnetosphere (Piper, Zmuda, Bostrom, O'Brien 1962).

Figure 5 shows three spectra of the July 12, 1961 event at 14, 31, and 53 hours after the flare, derived from measurements with Injun I, with balloons in Minnesota and with riometers in Kiruna, Sweden (Freier and Webber 1963). Exponential rigidity spectra according to Freier and Webber are assumed. We recognize that this event had high intensities only at very low energies. The part of the spectra above 100 Mev lies far below the proton intensities in the inner belt.

From the time profiles (fig. 6) derived from the spectra based on the intensities $E > 1$ Mev of Piper, et al., $I_o{}^*$, and on the values of $P_o{}^*$ of Freier and Webber, it can be noted that the highest energy part decreases steadily with time in intensity; the lowest energy part consisting of particles $E > 1$ Mev rose during a few hours by a factor of 30 above prestorm intensities and then declined steadily in a time comparable to the duration of the main phase of the magnetic storm. The maximum intensity $E > 1$ Mev is 33,000 p/cm^2-sec-ster, in the same order of magnitude as during November 1960, although the event was of much smaller size in duration and in content of higher energy particles.

The low energy particle intensity decreases very slowly and shows a second peak during the July 18 event, 5 days later.

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*The integral spectra are assumed to have the form: $I = I_o \exp - \frac{P}{P_o}$ where I is the integral flux of particles/cm^2-sec-ster having rigidity $\geq P$. I_o, the intensity of particles above low rigidity, and $1/P_o$, the slope of the rigidity spectrum, are functions of time.

If the low energy fluxes are integrated over the time in each of the events, November 12, 1960 and July 12, 1961, the following particle numbers/cm^2 are obtained:

	$E > 200$ kev	$E > 1$ Mev
November 12, 1960	2.8×10^{11} cm^2	7×10^{10} cm^2
July 12, 1961		1.8×10^{10} cm^2

If we intend to estimate the number of particles associated with energetic events and magnetic storms for a longer period of solar activity, as for instance, the $1\frac{1}{2}$ years - May 1959 to November 1960 - we have to make assumptions about the flux during the events for which these low energy particles were not directly measured, that is, May 1959 through May 1960.

A natural assumption appears to be that all low and medium energy proton events or event groups, showing high riometer absorption and accompanied by large magnetic storms, contain these low energy particles in intensities comparable to those observed in November 12, 1960 and July 12, 1961.

If we assign to strong riometer events $\geqq 20$ db of long duration accompanied by severe storms, the particle fluxes of November 12, 1960 (in the 1 Mev range), to those PCA events of ≈ 12 db of short duration with $K_p > 7^*$ the 1 Mev fluxes

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$^*K_p$ is a quasilogarithmic measure of the range of the most disturbed force component during the three-hour interval. Converted into the conventional three-hour equivalent planetary amplitudes, a_p, in the unit 2 gamma, $K_p = 7$ - corresponds to $a_p = 111$, $K_p = 8$ - to $a_p = 179$, $K_p = 9$ - to $a_p = 300$ (= 600 gamma, 1 gamma = 10^{-5} gauss). Ref. Bartels, F., Annals of the IGY4, 227-236 (1957).

of July 12, 1961, we obtain as the total numbers for the $1\frac{1}{2}$ year period: (See table III.)

$E > 200$ kev	$E > 1$ Mev
1.4×10^{12} p/cm^2	4×10^{11} p/cm^2

It is still difficult to say whether the above numbers for the period from May 1959 to November 1960 are an overestimate or an underestimate. Since this "cosmic ray" plasma or high energy tail of the solar plasma seems to be associated with magnetic storms, such particles may have been contained also in other intense plasma streams produced by flares in 1959 and 1960, where no higher energy particles were detected, insofar as the magnetic storms were preceded by Type IV radio noise. The Type IV radio noise is generally interpreted as synchrotron noise and therefore considered as proof that particles are accelerated during the outburst on the sun. This assumption that all "Type IV" magnetic storms contain such particles would increase the above number by a factor of 2 to about 10^{12} p/cm^2 $E > 1$ Mev. On the other side in some events such as July 12, 1961, or September 30, 1961, the latter measured outside the magnetosphere onboard Explorer XII (Hoffmann, Davis, and Williamson 1962) the low energy particle flux was limited mainly to the time before and after the sudden commencement of the magnetic storm. The period of intense low energy flux may thus have been shorter than the duration of the strong riometer absorption.

These uncertainties place the particle number $E > 1$ Mev which may contain a significant percentage of He and heavier nuclei somewhere between 10^{11} p/cm^2 and 10^{12} p/cm^2.

III. EFFECTS ON MATERIAL OF THE LOW ENERGY PROTON FLUXES

In discussing effects on materials of such amounts of particles which, in this approach, might be considered as consisting only of protons, we have to realize that the penetration depth of protons of 1 Mev is very low and that the fluxes are just of such order of magnitude that only unprotected most sensitive materials like unprotected solar cells, transistors, glass surfaces, or sensitive plastics like Teflon in very thin sheets, are permanently affected.

For orientation purposes in table IV,* fluxes or doses which affect such materials are listed. For instance, at 4×10^{11} p/cm^2 sensitive transistors with large base width, such as low frequency GE-transistors, show 50 percent decrease in gain (Hulten et al. 1961, Honeker and Bryant 1962); field transistors have a 20 times higher tolerance limit.

Certain glasses already show coloration at lower doses. The sensitivity varies, however, over a wide range (Jaffe and Rittenhouse 1962, Keister 1962). Thus by proper selection no serious difficulties should be encountered. Furthermore, the ultraviolet may have stronger effects than the particles.

Teflon (Tetrafluorethylene) is exceptionally sensitive. It will already become useless as an isolator at 3×10^{11} p/cm^2 and is even affected in its mechanical qualities at such low doses. For contrast Mylar polystyrene is still usable at doses higher by a factor of 1,000 to 10,000.

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*To tables IV and V: At minimum energy loss S_{min}, i.e., at relativistic velocities a number of 3.2×10^7 protons/cm^2 produces 1 rad or 100 erg/gr of energy absorption in water. An average energy loss of protons of 10 times S_{min} is used in tables IV and V for conversion of flux into dose. This is the energy loss of protons of about 30 Mev kinetic energy. For low energy protons ($\approx$1 Mev) the energy loss is 100 times the minimum or 10 times greater.

Table V* shows that mechanical damage on organic materials occurs in general at much higher doses. (Carroll and Bolt 1960).

Changes in absorptivity and emissivity of coating material are also expected at much higher doses of about 100 megarad. In coatings which are commonly sensitive to ionization and not to displacements, the effects of ultraviolet should again be more important than the effects of these particles.

Transient effects, of course, can occur at low proton doses and may be of considerable importance. As example, charge storage and successive pulse discharges in mylar during irradiation might be mentioned. These discharges are observed to occur at penetration of about a number of $1 \times 10^{12}/cm^2$ of 1 Mev electrons through 6μ mylar coated by thin aluminum layers on both sides,* independent of dose rate. Since most electrons of 1 Mev penetrate these thicknesses, considerably less protons of few Mev, which stop in the mylar because of lower range, should have the same effect.

It is outside the scope of this brief survey to go into detail on possible effects. The intent is merely to direct attention to the existence and to further exploration of this low energy particle radiation, occurring not only within the belts or within auroral latitudes near the earth but also in interplanetary space.

CONCLUDING REMARKS

The higher energy part of the solar flare spectra ($E > 20$ Mev) produces inside low shielding doses, which should be mainly important for effects on men or transient effects on sensitive electronic or measuring devices except on

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*Personal communication by H. Heyson, NASA Langley Research Center.

photo films. In an orbit in earth distance from the sun the doses behind low shielding (1/2 g/cm^2) are estimated to have been in the order of some 1000 rad on the surface of a body phantom during $1\frac{1}{2}$ years of high solar activity May 1959 to November 1960. In most events the dose or intensity falls off very fast with increasing shield thickness or with increasing depth in the body. A value of 30 - 40 rad in the center of a spherical phantom of 20 cm radius is estimated for the same period, not including galactic cosmic radiation.

The time integrated flux of low energy protons in the 100 kev and Mev range accompanying flare proton events is estimated to have been near the earth's orbit by 2 to 3 orders of magnitude higher for the same period. In earth distance from the sun, these transient fluxes had the same order of magnitude as the permanent maximum fluxes of low energy protons trapped in the belts. For long-term excursions during solar activity years the low energy protons may have to be taken into account with respect to the selection of surface materials and protection of sensitive devices especially if the spacecraft approaches the sun more closely.

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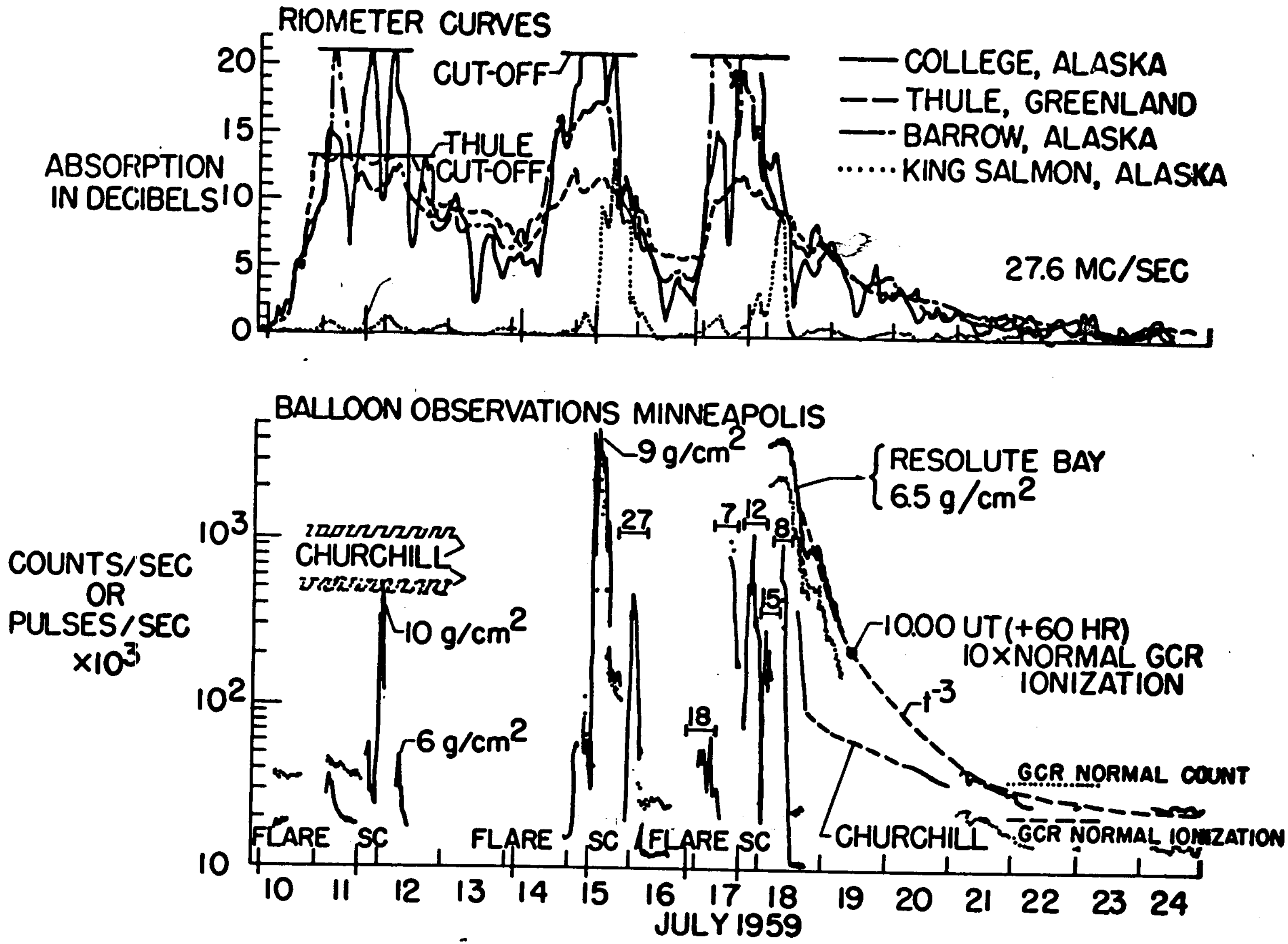

Figure 1.- Riometer records and balloon measurements during the July 10, 14, and 16 solar events.

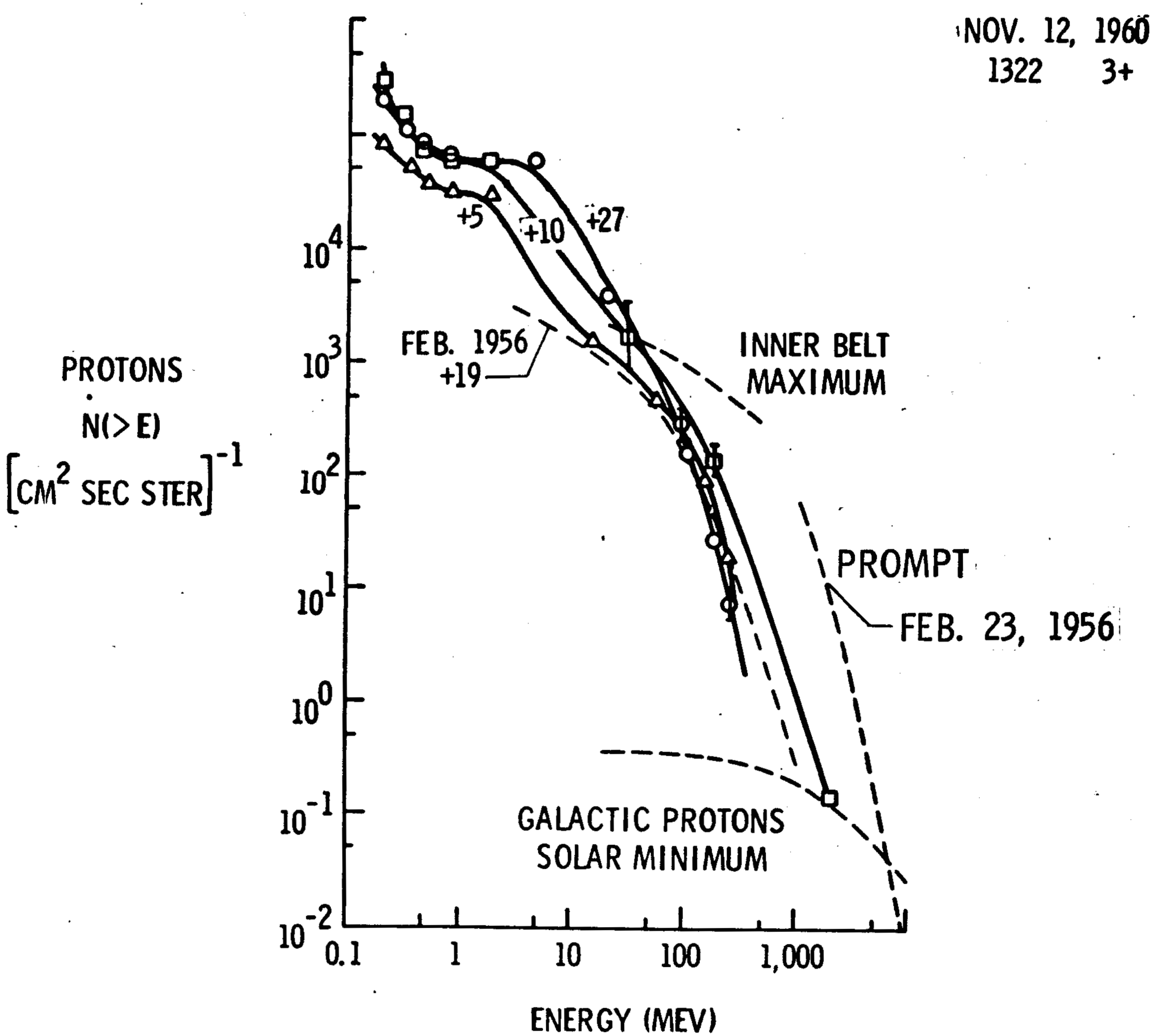

Figure 2.- Integral energy spectra of solar cosmic rays during February 23, 1956 and November 12 and 13, 1960. For comparison the integral spectra of inner belt protons and galactic protons are indicated.

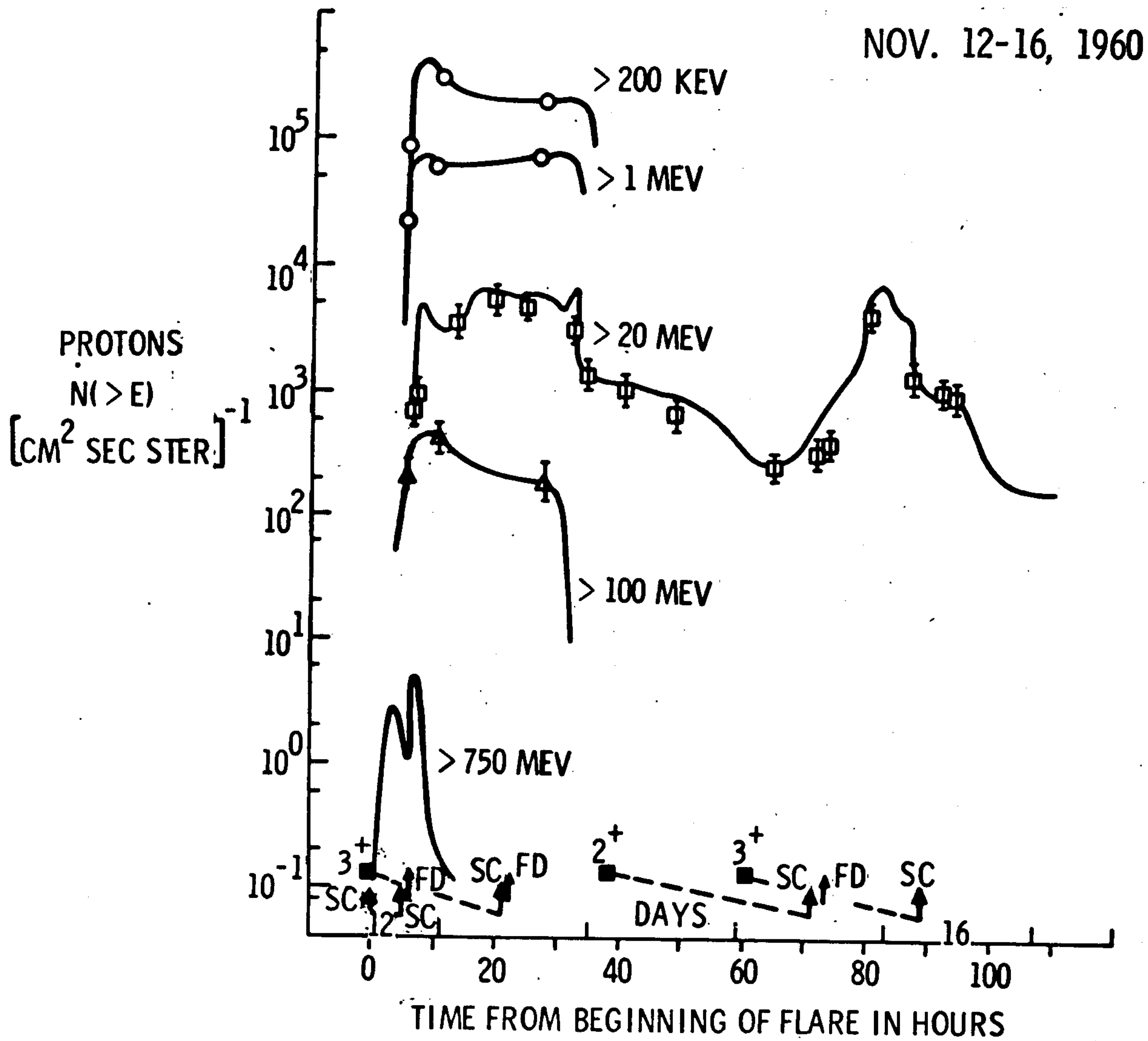

Figure 3.- Time profiles of intensities of particles above different energies during the November 12, 1960 event.

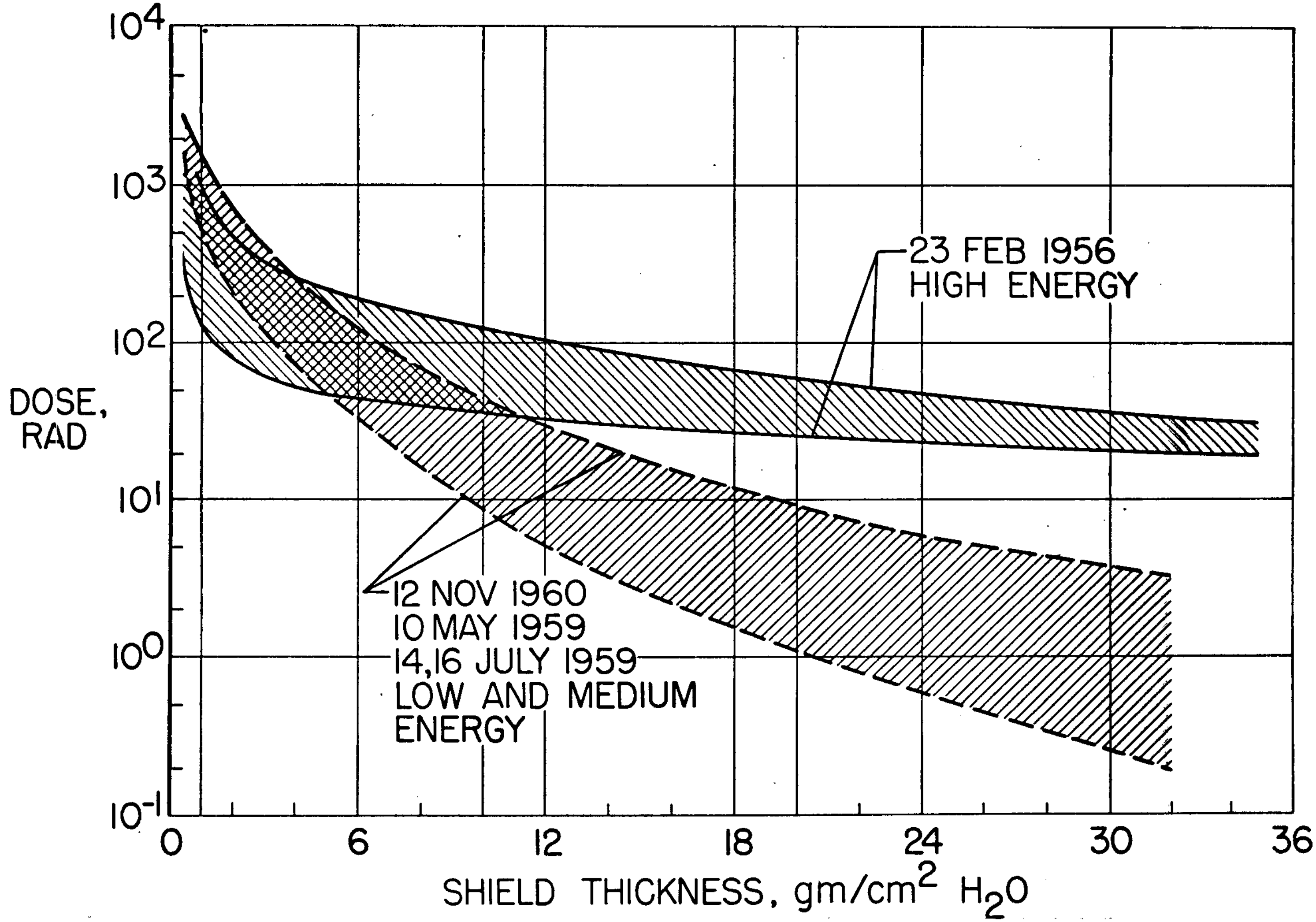

Figure 4.- Upper and lower limits of flare proton doses in the center of spherical shields for extreme events. The doses are calculated, neglecting selfshielding and secondaries, on the basis of the spectra and their time variations given in the references and in figures 2 and 3.

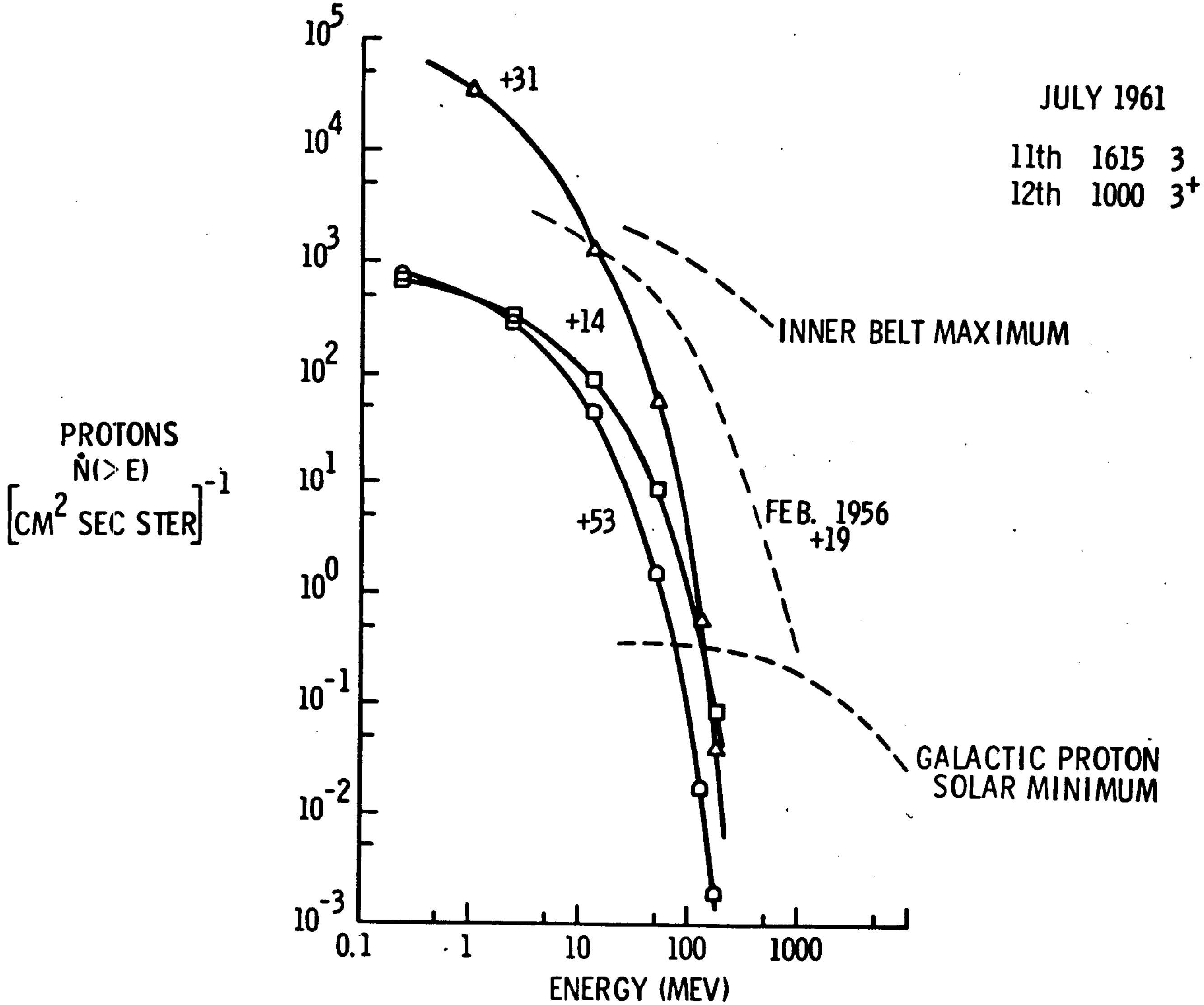

Figure 5.- Spectra at different times during the low energy events July 11 and 12, 1961.

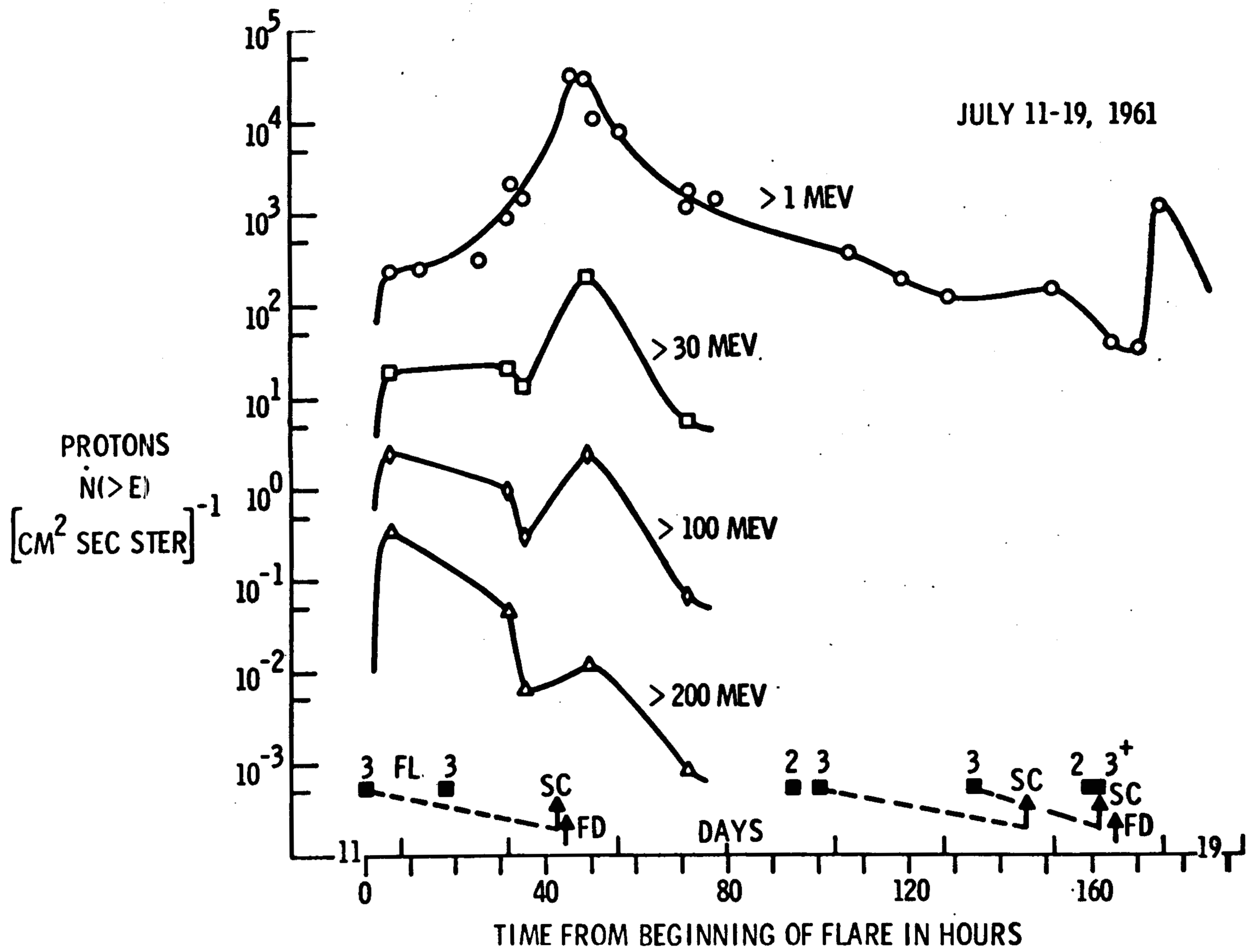

Figure 6.- Time profiles of intensities during July 11-14, 1961. (According to Pieper et al., and Freier and Webber.)

E KIN	IN Al ($\rho = 2.7$)		IN H_2O ($\rho = 1$)
200 KEV	0.3 mg/cm^2	1.1 μ	2.5 μ = 0.1 mil
1 MEV	3.5 mg/cm^2	13 μ	25 μ = 1 mil
20 MEV	0.4 g/cm^2	0.15 cm	0.3 cm
100 MEV	10 g/cm^2	3.7 cm	7 cm
1000 MEV	400 g/cm^2	1.72 m	3.4 m

TABLE I.- RANGES OF PROTONS OF DIFFERENT ENERGY

(NEGLECTING SELF-SHIELDING)

OUTER SHIELD	0.5 g/cm^2			1 g/cm^2			2 g/cm^2			6 g/cm^2			20 g/cm^2	
* DOSE, LIMITS	RAD UPPER	RAD LOWER	1/2	RAD UPPER	RAD LOWER	1/2	RAD UPPER	RAD LOWER	1/2	RAD UPPER	RAD LOWER	1/2	RAD UPPER	RAD LOWER
EVENTS:														
MAY 10, 59	≈ 3,700		≈ 1,850	≈ 1,100		≈ 550	≈ 360		≈ 180	≈ 38		≈ 19	≈ 1.1	
JULY 10, 59	≈ 1,000		≈ 500	≈ 450		≈ 225	≈ 240		≈ 120	≈ 47		≈ 23	≈ 3.8	
JULY 14, 59	2,400	1,600	1,000	1,020	780	450	458	305	190	105	70	44	8.7	5.8
JULY 16, 59	2,600	1,300	975	1,000	500	375	400	200	150	76	38	29	5.5	2.7
Σ JULY			≈ 2,475			≈ 1,050			≈ 460			≈ 96		
NOV. 12, 60	≈ 2,700		≈ 1,350	≈ 1,500		≈ 750	≈ 680		≈ 340	≈ 115		≈ 58	≈ 10.5	
NOV. 15, 60	≈ 1,300		≈ 650	≈ 750		≈ 375	≈ 300		≈ 150	≈ 57		≈ 29	≈ 5	
Σ DOSES	13,700	11,600	≈ 6,325	5,820	5,080	≈ 2,725	2,438	2,085	≈ 1,130	438	365	≈ 202	34.6	28.9

TABLE II.- SUMMARY OF FLARE DOSES FOR THE PERIOD OF $1\frac{1}{2}$ YEARS MAY 1959 TO NOVEMBER 1960. IN THE THIRD COLUMN OF EACH SECTION SKIN DOSES ARE GIVEN, TAKING SELFSHIELDING OF MAN'S BODY INTO ACCOUNT BY A FACTOR OF 1/2. THE DOSES IN THE LAST COLUMN ARE DOSES IN THE CENTER OF A SPHERICAL BODY PHANTOM OF 15 cm RADIUS INSIDE A SPHERICAL SHIELD OF $5 g/cm^2$ THICKNESS

*The doses are derived from measurements within the earth magnetosphere, which was disturbed and may have modulated the intensities during part of the time of the events. In free space the doses might have been higher than the upper limits given in the table.

EVENT	db	DURATION OF MAX. PHASE	k_p	P/cm^2 >200 KEV	P/cm^2 >1 MEV
NOV. 12, 1960	>20	24 hr	9	2.8×10^{11}	7×10^{10}
JULY 12, 1961	≥14	≈12 hr	8+		1.8×10^{10}
		MAY 59 – NOV 60			
MAY 10	>20	36 hr	6	1.1×10^{12}	2.8×10^{11}
JULY 10, 14, 16 1959	>20	≈ 3 × 24 hr	7, >9, 9		
APRIL 28 - MAY 1960	12	6-12 hr (1 OF 4 EVENTS)	9		3.6×10^{10}
MAY 6-15	12	6-12 hr	9		
NOV 12, 15	≈20	24, 10 hr	9,8	2.8×10^{11}	9×10^{10}
				1.4×10^{12}	$4 \times 10^{11}/cm^2$

TABLE III.- TIME INTEGRATED FLUXES OF LOW ENERGY PROTONS E > 1 Mev DURING THE PERIOD MAY 1959 TO NOVEMBER 1960 UNDER THE ASSUMPTIONS OUTLINED IN THE TEXT

MATERIAL	PRIMARILY AFFECTED BY	$\frac{\text{PROTONS}}{\text{cm}^2}$	RAD	DAMAGE	AUTHOR
(1) SOLAR CELLS; TRANSISTORS: Ge (LOW FREQUENCY) FIELD TRANSISTORS	DISPLACEMENTS	4×10^{11} - 8×10^{12}	10^5 - 2×10^6	50 % DECREASE IN GAIN	HULTON HONECKER
(2) GLASSES	DISPLACEMENTS + IONIZATION	3×10^9 - 3×10^{14}	10^3 - 10^8	OPTICAL TRANSMISSION AFFECTED	JAFFE RITTENHOUSE KEISTER
PLASTICS:					
TEFLON	IONIZATION	3×10^{11}	10^5	ELECTRICAL (USELESS) MECHANICAL	KEISTER
MYLAR POLYSTEREN	IONIZATION	3×10^{15}	10^9	STILL USABLE	JAFFE RITTENHOUSE

TABLE IV.- THRESHOLD DOSES FOR EFFECTS ON MATERIALS

MATERIALS	PRIMARILY AFFECTED BY	PROTONS / cm^2	RAD	DAMAGE		AUTHOR
				ELASTOMERS	PLASTICS	
(3) ORGANIC MATERIALS MECHANICAL DAMAGE	IONIZATION	3×10^{12}	10^6	SOME SOFTEN	SOME SOFTEN	CAROLL BOLT
			10^7	COMMON ONES USABLE	COMMON ONES USABLE	
			10^8	MOST BECOME INELASTIC	MOST LOOSE TENSILE STRENGTH	
			10^9	ALL HARDEN		
		3×10^{16}	10^{10}		ALL EMBRITTLE	

TABLE V.- DOSES AND THEIR EFFECTS ON MECHANICAL QUALITIES